Agricultural planning in sugarcane planting areas

Adriana Cristina Cherri
Departamento de Matemática, FC, UNESP, Bauru SP, Brasil.
adriana@fc.unesp.br

Andrea Carla Goncalves Vianna
Departamento de Computação, FC, UNESP, Bauru SP, Brasil.
vianna@fc.unesp.br

Rômulo Pimentel Ramos
PG Energia na Agricultura, FCA, UNESP, Botucatu SP, Brasil.
romulo.pimentel@hotmail.com

Helenice de Oliveira Florentino
Departamento de Bioestatística, IB, UNESP, Botucatu SP, Brasil.
helenice@ibb.unesp.br

Abstract

The sugarcane harvesting process uses extensively mechanization that promotes rational and economical resources, increases operational efficiency and reduces environmental impact. On the other hand, the mechanized harvesting must be properly planned, starting with the preparation of the area intended for planting. In this paper, we propose a methodology for planning the division of the plantation area into rectangular plots and for their allocation in order to perform mechanized harvesting. The problem is represented as a two-dimensional cutting stock problem and it is solved by the AND/OR graph method. Experimental results based on real data are showed and discussed.

Keywords: sugarcane; planting planning; AND/OR graph approach; OR in Agriculture.

1 Introduction

Sugarcane has important highlight in the economy of some countries, mainly in Brazil. Currently, Brazil is the largest producer of sugarcane and the largest exporter of sugar and ethanol in the world. Due to the growth in the consumption of ethanol and sugar, the production process has undergone important changes, mainly in harvesting methods that must became all mechanized (UNICA, 2007).

To obtain a good performance of the sugarcane harvesting machine, the planting area must be planned. This planning begins with soil preparation, determination of the most appropriate row spacing to avoid stump trampling and to adopt suitable sugarcane varieties for mechanical harvesting (Benedini and Donzelli, 2007). For maximum efficiency of the harvesting machine and minimal costs it is necessary to plan the plot design, that must be rectangular, and sugarcane rows, in such a way to perform the fewest possible maneuvers (Anselmi, 2008). According to Benedini and Conde (2008), the plots should have furrow length of 500-800 meters and width of 150-400 meters. For Rossetto and Santiago (2012), the spacing between rows should be 1.5 meters. The plots are generally subdivided based on topography and soil homogeneity and should present an average area of 10 and 20 hectares.

Zhou et al. (2014) developed a planning method that generates a feasible area coverage plan for agricultural machines executing non-capacitated operations in fields containing multiple obstacle areas. The problem was formulated as a traveling salesman problem and it was solved using ant colony algorithmic heuristic.

To guarantee the efficiency of the mechanized harvesting, we propose a methodology for planning the division of the planting area in plots and their allocation in the area. Rectangular plots are generated and allocated in planting areas minimizing the number of harvesting machine maneuvers. The methodology proposes approximating the real problem in a two-dimensional cutting stock problem (2DCSP). To solve the problem of selecting and allocating the plots the AND/OR graph proposed by Morabito et. al (1992) was used. Since some planted areas have regions where it is not possible or permitted to plant sugarcane, some peculiarities of the 2DCSP were considered, so that no plot is allocated in these regions. Computational experiments were performed with real cases and are discussed.

The remainder of the paper is organized as follow: in Section 2, the generation of the plots is described. In Section 3, we present the briefly description of the AND/OR graph approach, which is the strategy used to select and allocate plots in the planting areas. Section 4 shows how the interpretation of the solutions presented by the AND/OR graph approach is carried out. In Section 5, solutions for some real cases are presented. Conclusions are presented in Section 6.

2 Problem description

Consider an available area for planting sugarcane of H hectares and let J be the set of all possible plots that can be allocated to this area. The plot generation problem is defined as:

A planting area must be divided into rectangular plots with dimensions (l_j, w_j), where l_j is the length and w_j is the width of the plot $j \in J$, in order to increase yield, reduce traffic and minimize the maneuvers of the sugarcane harvesting machine.

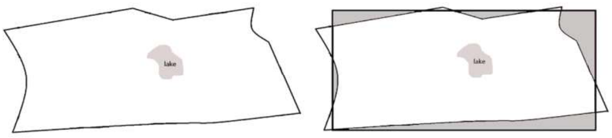
According to the literature, an acceptable space between sugarcane rows is 1.5 meters. Thus, the calculation of the number of harvesting machine maneuvers in the plot j is given by $\lfloor \frac{w_j}{1.5} \rfloor - 1$, where $\lfloor x \rfloor$ indicates the largest integer not greater than the corresponding element x. Our objective is minimize the number of harvest machine maneuvers in the plot j and, simultaneously, taking advantage of the plantation area with constraints on the dimensions and in the area of the plots. For this, we impose lower (l_{low} and w_{low}) and upper (l_{upp} and w_{upp}) bounds on the lengths and widths of the plots and also, on the areas of the plots ($Area_{low} \leq l_j w_j \leq Area_{upp}$). To ensure that the plots have the form of a long rectangle, we consider the width (w_j), $j \in J$, of the plot smaller than or equal to a percentage (p) of the length (l_j), $j \in J$, that is, $w_j \leq p l_j$.

According to the recommendations of the mills (Cervi, 2013), the area of the plot ($l_j w_j$), $j \in J$, must be smaller than or equal to 15% of the total area to be planted ($l_j w_j \leq 0{,}15 H 10^4$) and the sum of the plot areas be less than or equal to the total area.

Using all the recommendations cited in this section, the length and width of the plots were generated and combined, originating rectangles (plots). With the suitable plots generated, the AND/OR graph approach was used to select and allocate the plots in order to minimize the maneuvers of the sugarcane harvesting machine.

3 Plot Allocation Using the AND/OR Graph Approach

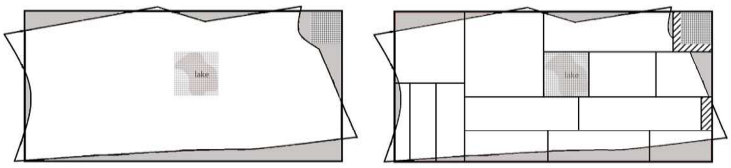
To solve the rectangular plot allocation problem in a sugarcane plantation area, this problem will be related to the 2DCSP (Gilmore and Gomory, 1965). This problem consists of allocating small rectangular pieces in larger rectangular plates. For this, the irregular plantation area is manually approximated to the two-dimensional plate, and the plots are considered as the rectangular pieces. The allocation of plots in the plantation area is similar to the generation of a cutting pattern in the cutting stock problem. Figure 3.1 illustrates the representation of one irregular area and the approximation made with a rectangular plate.



(a) (b)

Figure 3.1: (a) Example of an irregular region; (b) Approximation with one rectangular plate.

Besides the irregular form, some areas used to planting sugarcane can contain preservation areas, constructions projects, lakes or other areas where the plot allocation is not allowed. Due to this restriction in some areas, a particularity of the 2DCSP was considered, including the possibility of a defect in the plate (Vianna and Arenales, 2006). Figure 3.2 shows the same region presented in Figure 3.1 with some areas considered as defects in the plate (hatched rectangles). Plots are not allocated in these areas.



(a) (b)

Figure 3.2: (a) Identification of the defect; (b) Possible plot allocation on the plate/region.

To solve the 2DCSP with a defective plate, Vianna and Arenales (2006) proposed a modification of the AND/OR graph presented by Morabito *et al.* (1992). In the AND/OR graph, the cutting patterns are represented as a complete path in a special graph.

An AND/OR graph is a directed tree with a set of nodes (rectangles) and a set of directed arcs (cuts). In our problem, the cuts will be consider guillotine type, that is, when the plate is cut, two new rectangles/plates are generated. An OR-arc chooses between several arcs that emerge from a node and an AND-arc establishes a relationship between both branches of the chosen arc.

The cutting patterns are generated using the AND/OR graph verifying in each node all the cut possibilities until the same rectangle is reproduced (0-cut). At this point, no further cut is made. The cuts on a plate (vertical or horizontal) can be restricted, without loss of generality, to a finite set, called the "discretization set", which is formed by non-negative linear combinations of the item sizes. Details about the discretization set can be found in Herz (1972). Using the AND/OR graph, it is possible to represent a cutting pattern as a complete path in a graph and enumerate the sizes implicitly with the objective of finding the optimal solution.

Cutting patterns in a defective plate are solved using an AND/OR graph similarly to the case without defects, with minor modifications (Vianna and Arenales, 2006). The most important modification in the AND/OR graph is realized during the construction of the discretization set. The defects are represented by one or more rectangles with a fixed position (Figure 3.2). The discretization set provides position of the cuts for the plate and it is applied until a defect is found. From the localization of the defect, the discretization set beginnings again following sequentially until a new defect is found or the discretization set is exhausted. Details on the implementation of the AND/OR graph with defective plate can be found in Vianna and Arenales (2006).

After approximating the planting area using a plate and defining the allocation of all possible plots using the AND/OR graph approach, the next step consists of approximating the solution to the real area of sugarcane planting. The treatment of this solution is presented in Section 4.

4 Treatment of the Solution

After the plot allocation in sugar planting areas, a post-optimization process is manually realized to approximate the solution generated by the AND/OR graph approach to the real area. From Figure 3.2(b), the planting area with defined plots is presented in Figure 4.1.

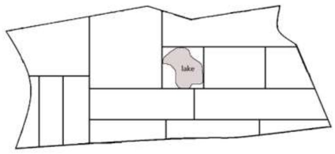


Figure 4.1: Solution adapted to planting area.

Comparing the solutions presented in Figure (4.1) and (3.2b), it is possible to see that the plots in the edge of the defined region are not rectangular. This is natural since the planting area is not a regular region.

During the post-optimization process, some generated waste (large hatch in Figure (3.2b)) are incorporated into the nearest allocated rectangle. However, the limits on the dimensions of the plots are respected within an acceptable level of tolerance.

Considering agricultural management practices, the cane rows should be aligned with terrain contour lines to minimize soil erosion. Although our strategy provides straight cuts, it can give a good idea to the manager during the division of the plantation area and, from the proposed approximating the plots in rectangles, it is possible make the better adjustment considering the terrain contour lines.

5 Computational Experiments

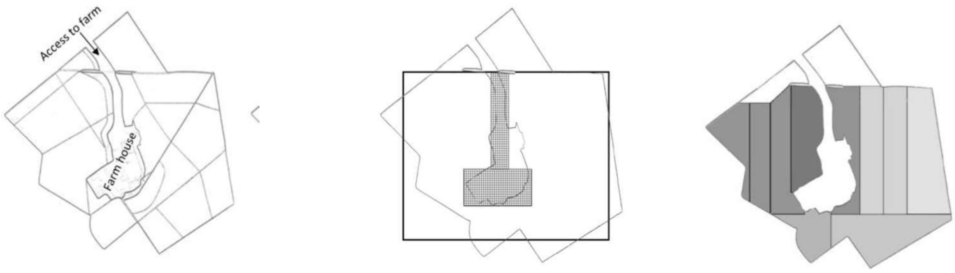
To analyze the performance of the proposed methodology, we considered two real regions (slope less than 12%) on a farm located in the interior of the São Paulo state, Brazil. Currently, this farm is administered by a mill and will reformulate the planting area for mechanized harvesting. The first region has an area of 178.84 hectares (map1) and the second region with 101.69 hectares (map2). For these maps, defects were defined.

To obtain the solution, first we generate the set J of the plots using the strategy presented in Section 2. Next, plots from J are selected by the AND/OR graph, and the plot allocation is performed, allowing 90° rotation of the plots to be allocated. Finally, the solution is adjusted (post-optimization).

The plot generation was performed using the values proposed by Benedini and Conde (2008) and that were acceptable by the mill manager: l_{low} = 500 meters, l_{upp} = 800 meters, w_{low} = 150 meters, w_{upp} = 400 meters, $Area_{low}$ = 80,000 meters and $Area_{upp}$ = 190,000 meters. We also define p = 50 to guarantee that the generated rectangles are elongated and the machine harvesting reaches its full potential.

The algorithm used to generate and allocate the plots in the planting area was created in Pascal-language and and executed on a PC equipped with an Intel Core 2 Duo processor.

Figure 5.1(a) shows map 1 with the regions currently used for sugarcane planting and the plots divided for manual harvesting. According to this map, there is a farmhouse and an access path to the farm in this region. To avoid plot allocation in these areas, we define defects in these places (Figure 5.1(b)). Certainly, other defects could have been defined. Still in the Figure 5.1(b), observe that there is a large region covered by the rectangle that does not belong to map 1, and there is a large region in the map that is not covered by the rectangle. This region has a shape that is similar to the rectangle and dimensions that satisfy the imposed limits, thus, it will be treated during the post-optimization process. The planting area can be rotated or be covered by a different rectangle if it is attractive or necessary. Figure 5.1(c) shows the final solution to the real planting area, after adjust the solution generated by the AND/OR graph.



(a) (b) (c)

Figure 5.1: (a) Map 1 with plots currently allocated; (b) Rectangle adjustment and definition of the defect in map 1; (c) Final solution in map 1.

To analyze the solution, we compare the number of maneuvers that the harvesting machine performs using solution illustrated in Figure 5.1(c) with the current plot division presented in Figure 5.1(a). With the plots defined in Figure 5.1(a), the number of maneuvers was 3,694, and after applying our methodology (Figure 5.1(c)) the number of maneuvers was 2,193. This solution represents a reduction of 40.63% in the number of maneuvers realized by the harvesting machine and, consequently, reductions in the time that the machine is used, the hours worked by the machine operator and an increase in fuel economy that also reflected in environmental benefits.

Figure 5.2(a) shows map 2 of the farm with the plots currently used. Figure 5.2(b) illustrates the rectangle approximation for the region. In this planting area, there are no nature preservation areas, construction areas, rivers, lakes or other areas that do not allow the allocation of plots. The defects were allocated only outside of the region. Figure 5.2(c) presents the final solution.

(a) (b) (c)

Figure 5.2: (a) Map 2 with plots currently allocated; (b) Rectangle adjustment and definition of the defect in map 2; (c) Final solution in map 2.

With the defined defects in the map 2, The number of maneuvers of the harvesting machine using the solution presented in Figure 5.2(c) is 1,011, representing a reduction of 63.91% compared with the current allocation (Figure 5.2(a)).

During the harvest of sugar cane, take optimally the necessary resources can generate higher profits. Planning plots for planting, help to reduce the number of maneuvers of the harvesting machine, reduces the time that the harvesting machine is used, reduce the hours worked by the machine operator, the consumption of fuel, among others. Furthermore, the planning of the harvest procedure has as consequence an important reduction of the environment impacts.

The results obtained were presented for the mill manager that stayed very satisfied. Thus, we consider the performance of the proposed strategy very good and well suited to assist mill managers in the planning of the sugarcane planting areas. For the allocations presented in this section, the computational time was acceptable in practice (about 10 seconds for the definition of each region).

6 Conclusions

In this paper, we proposed a strategy for dividing the planting areas into rectangular plots for mechanized sugarcane harvesting. In the proposed methodology, first the plots are generated with realistic dimensions, next the planting area is approximated by a rectangle and defects are defined. Thus, the AND/OR graph is used to select and allocate plots to this rectangle. A post-optimization process is carried out to approximate the solution obtained by the AND/OR graph to the real sugarcane planting area.

To verify the performance of the strategy, we use two real regions of one farm located in the interior of the São Paulo state, Brazil. Currently, this farm has a sugarcane plantation and will reformulate all area for mechanized harvesting. With our strategy, was possible a reduction of over 40% in the number of maneuvers of the sugarcane harvesting machines, compared with currently division of the plots. This reduction implies many economic and environmental advantages. When presented to the mill manager, the solutions met the expectations. We are sure that the proposed methodology can assist the mills managers in the planning of sugarcane planting areas or, due the flexibility of the strategy, it can be adapted and used to various planting areas.

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